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There is growing interest in the ecology of the Maya Forest past, present, and future, as well as in the role of humans in the transformation of this ecosystem. In this paper, we bring together and re-evaluate paleoenvironmental, ethnobiological, and archaeological data to reconstruct the related effects of climatic shifts and human adaptations to and alterations of the lowland Maya Forest. In particular, we consider the paleoenvironmental data from the Maya Forest area in light of interpretations of the precipitation record from the Cariaco Basin. During the Archaic period, a time of stable climatic conditions 8,000–4,000 years ago, we propose that the ancestral Maya established an intimate relationship with an expanding tropical forest, modifying the landscape to meet their subsistence needs. We propose that the succeeding period of climatic chaos during the Preclassic period, 4,000–1,750 years ago, provoked the adaptation to settled agrarian life. This new adaptation, we suggest, was based on a resource management strategy that grew out of earlier landscape modification practices. Eventually, this resulted in a highly managed landscape that we call the Maya Forest Garden. This highly productive and sustainable system of resource management formed the foundation for the development of the Maya civilization, from 3,000 to 1,000 years ago, and was intensified during the latter millennia of a stable climatic regime as population grew and the civilization developed. These strategies of living in the forest evolved into the milpa cycle—the axis of the Maya Forest garden resource management system that created the extraordinary economic value recognized in the Maya Forest today.

Key words: *resource management, ancient Maya, Maya Forest, Holocene adaptation.*

Crece el interés por la ecología de la selva maya, pasado presente y futuro. En este artículo, reevaluamos los datos paleoambientales, etnobotánicos y arqueológicos de la selva maya y los sedimentos marinos de la cuenca del Cariaco para reconstruir las relaciones entre clima y cultura en las tierras bajas del area cultural maya. Proponemos que el jardín forestal maya y el ciclo de la milpa evolucionaron como sistema de manejo de recursos, como adaptación a los cambios ambientales y climáticos. Los datos indican que durante el Arcaico, un periodo de condiciones climáticas estables de 8,000–4,000 años atrás, los ancestros de los mayas establecieron una relación íntima con el bosque tropical en expansión, modificando el paisaje para satisfacer sus necesidades de subsistencia a través de el jardín forestal y el ciclo de la milpa. Sugerimos que el desarrollo de la civilización maya desde hace 4,000 a 1,750 años sucedió después de un período de caos climático que forjó la adaptación que condujo a la vida agraria sedentaria basada en una estrategia de manejo de recursos naturales del jardín forestal maya. Además, los mayas intensificaron este sistema altamente productivo y sustentable mientras creció la población durante el auge de su civilización que seguía prosperando hasta la llegada de los europeos en el Siglo XVI. Esta estrategia de vida en el bosque que evolucionó hacia el ciclo de milpa, eje del sistema maya de manejo de recursos, creó y conservó el bosque cuyo extraordinario valor ecológico y económico reconocemos hoy en día.

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Introduction

The Maya Forest, home to the ancient Maya civilization, is a lowland tropical ecosystem that extends from southern Mexico into the Yucatan Peninsula, the Petén of Guatemala, and Belize (Nations 2006; Figure 1). Once thought to be ''natural'' and ''pristine,'' ecologists and resource managers, largely relying on archaeological data, now recognize that humans have influenced this ecosystem for many millennia (e.g., Denevan 1992; Whitmore and Turner 1992). Today, intense human influence in the form of cattle ranching and logging threatens the viability of this tropical ecosystem (Harvey et al. 2008; Nations 2006; TNC 2009).

Despite the recognition of anthropogenic impacts on the Maya Forest, there is less agreement on the timing and nature of these impacts (Webster 2002). In his popular synthesis on societal collapse, Diamond (2005), for instance, posits that lowland Maya interactions with the surrounding forest, in particular deforestation associated with agriculture, have been largely destructive in nature to the ultimate detriment and ''collapse'' of the Classic Maya society around 1,100–1,000 years ago. This popular view of extensive forest destruction by the Maya during the height of the civilization (1750–1100 BP) is based on its widespread acceptance in the scholarly literature (e.g., Turner 1990; Webster 2002).

Ethnobiologists working with the Maya today, however, hold an alternative view of Maya interactions with their surrounding forest where the language and knowledge of forest ecology, the management of its resources, and the traditional practice of ''forest gardening'' support a model of long-term, sustainable management of the forest by the Maya (e.g., Alcorn 1981; Atran 1993; Campbell et al. 2006; Fedick et al. 2008; Ford 2008; Gliessman 1982; Gómez-Pompa 2004; Gómez-Pompa and Kaus 1992; Johnston 2003; Kashanipour and McGee 2004; Nigh 2008; see also VanDerwarker 2005, 2006; Voorhies 1982). Such long-term sustainable use of the forest is exemplified by the cultivation of cacao in the Yucatan (Gómez-Pompa et al. 1990) and the managed succession that promotes wildlife habitat in the Petén (Ferguson and Griffith 2004; Ferguson et al. 2003). Clearly, resolving the relative value of the two models, the Maya as managers versus the Maya as destroyers of their ecosystem, is an essential step in understanding how to conserve this threatened ecosystem today.

In this paper, we propose a new hypothesis about the nature and timing of Maya long-term interaction with their surrounding forest ecosystem. We start with the assumption that the rich ecological knowledge and practices of the present-day Maya reflect, to some degree, the traditional knowledge of their pre-contact ancestors. We then turn to a review of the paleoecological data that we believe do not support a model of Maya destruction of the forest at the height of Maya civilization, or at any other time. Rather, we suggest that the data are consistent with a long and dynamic ecological history in which forest structure and composition were gradually influenced by people, beginning with the Archaic period ancestors of the Maya and culminating with the Maya of today. In our model, climate prompted an adaptation that created the highly productive, managed Maya Forest that ethnobiologists observe today. We suggest that it was the creation, intensification, and maintenance of this resource-rich ecosystem that underwrote the development of the Maya civilization.

Based on our reexamination of the archaeological and paleoecological evidence, we suggest that the ancestors of the Maya began adapting to their surrounding forest environment in the Archaic, beginning around 8,000 years ago (Colunga-Garica Martin and Zizumbo-Villareal 2004; Turner and Miksicek 1984). That is, contrary to the implicit view that the Maya settlements from 3,000 years ago represent the first occupants of the area (Deevey et al. 1979; Puleston and Puleston 1972; Rice 1996) and that human interaction with the forest began at that time, we suggest that modification of the forest was not limited to the period of the Maya civilization. Rather, we suggest such modification extended back into the Archaic, coeval with the emergence of the tropical forest ecosystem 8,000 years ago (Leyden 1984, 2002:88–93; see also Kellman and Tackaberry 1997:22–23). Furthermore, we propose that the forest adaptations of the Archaic peoples ultimately led to an intensively managed forest that fueled the development of the Maya civilization.

Our evidence for the establishment of this ancient system of agroforestry management is based on the same data that have been used as proof of Maya-induced deforestation (e.g., Binford et al. 1987; Deevey et al. 1979; Rice 1996, among others). We propose that the data are not consistent with evidence for human-induced environmental changes but instead support a model of long-term management of the forest by the Maya and their ancestors. We suggest that the remnants of this ancient resource management system are visible today both in the structure and composition of the Maya Forest and in the current resource management practices of the Maya (cf., Campbell et al. 2006; Emery and Thornton 2008; Ford 2008; Ford and Emery 2008).

Our reassessment of Maya Forest environmental history is based on the integration of paleoecological and archaeological evidence from the local Maya area in the context of the greater Circum-Caribbean region. Local evidence of environmental changes are drawn from the pollen and sediment record of the Petén Lake cores (e.g., Anselmetti et al. 2007; Binford et al. 1987; Deevey et al. 1979; Hodell et al. 2008; Leyden 2002; Rosenmeier et al. 2002; Vaughan et al. 1985), and marine sediment data from the Circum-Caribbean Cariaco Basin provide evidence of regional variability in the Holocene (Haug et al. 2001; Haug et al. 2003). We posit that initial changes in the structure and composition of the lowland Maya Forest, coupled with the regional precipitation data observed in these records, were driven primarily by climatic factors rather than, as commonly believed, by Maya agricultural practices.

We suggest the paleoenvironmental indicators used to argue for anthropogenic deforestation are better explained by the regional swings in excess and deficit precipitation recorded in the regional Cariaco sediment record between 4,000 and 2,000 years ago (Figure 2). That humans were not responsible for the initial changes in forests is further supported by the fact that the local forest transformations after 3,000 years ago are barely coincident with the first scattered permanent settlement of the Maya area. We offer an alternative hypothesis that the ancient Maya adapted to the environmental shifts by further changing the forest structure and composition to enhance productivity of valued plant taxa. That is, we argue that shifts in the paleoecological record, previously interpreted as evidence of the Maya denuding the forest, can be re-interpreted as evidence of forest management in the form of the Maya Forest garden.

We begin the paper with a description of the Maya Forest garden and demonstrate that it represents an adaptive management system linking the past to the present (Toledo et al. 2003). We then review the paleoecological record of climate and vegetation changes during the past 5,000 years, incorporating recent data from the Cariaco Basin (Haug et al. 2001) with previous paleoecological data from the Maya region (see Binford 1987; Brenner et al. 2002; Hodell et al. 2007; Rice 1996 for general summaries). Finally, in the light of these data, we review Maya culture history and conclude that climate change played a significant role in landscape transformations. The Maya's adaptation to climatic changes was to intensify the forest management system developed during the preceding millennia, a system that is still in place today.

The Milpa Cycle and The Maya Forest Garden

The Maya milpa cycle is an ancient system of land use that sequences from a closed canopy forest to an open field dominated by annual crops (the milpa), to a managed orchard garden, and then back to a closed canopy forest (Table 1; Nigh 2008; Wilken 1971, 1987). The resultant forest is a highly managed, anthropogenic landscape that we call the ''Maya Forest Garden.'' Far more than merely a type of farming, the milpa cycle is the axis of Maya natural resource management (Terán et al. 1998). A fundamental misconception of the milpa cycle is that fields are ''abandoned'' to lie fallow after several years of annual crop cultivation. In reality, in the ''high-performance milpa'' (Wilken 1971, 1987), fields are never abandoned even when they are forested. Thus, it is more accurate to think of the milpa cycle as a rotation of annuals with successional stages of forest perennials during which *all* phases receive careful human management (Gómez-Pompa 1987, 1991; Gómez-Pompa and Vazquez Yáñez 1981; Gómez-Pompa et al. 1990; Gómez-Pompa et al. 2003; Hernandez Xolocotzi et al. 1995; Nations and Nigh 1980; Nigh 2008; Terán et al. 1998).

The management of the milpa cycle is an essential tool for the creation and maintenance of the Maya Forest garden landscape over time and across space (Table 1). The cycle is initiated in closed-canopy forest when a modest 2–5 hectare clearing is made with cutting tools and fire, selecting for economic species and encouraging the resprouting of other species. In the following several years, annual cropping is practiced and fields are visually dominated by maize but also include many types of companion crops (Nations and Nigh 1980; Terán et al. 1998). As a cultivated field, the milpa has its own ecology of herbs, tubers, and plants that deter pests of the main crops, enhance soil nutrients, and maintain moisture in the soil (Gleissman et al. 1981). Even before this phase of annual crops is over, the selection of trees and bushes for the woodland stages begins. Human intervention is most intense during the early years of re-growth. Ecological studies have shown that events in these early stages largely determine the rate and floral composition of the later phases of succession (Chazdon 2008; Nigh 2008). Through enrichment planting and selection of woody species during the initial phases of the milpa, the Maya farmers shape the forest recovery to their needs.

The purposes of management vary according to the phase of the milpa cycle (Table 1). In the annual crop phase, production of food resources is the key

TABLE 1. The Milpa –Forest Garden Cycle.

Milpa Cycle	Dominant Plants[1]
Open milpa: Stages 1–2 (1–4 yrs; 4–7 yrs)	Cultigens: ~70 spp such as *Capsicum* spp. ***Chenopodium ambrosioides* L.**, *Cnidoscolus* spp., *Cucurbita* spp., ***Lycopersicon esculentum* Mill.**, *Phaseolus* spp., *Xanthosoma yucatanense* Engl., ***Zea mays* L.** Several other genera found in Leguminosae Non cultigens**: *Ambrosia* spp.**, ***Cecropia* sp.**, ***Mimosa* sp.**, ***Trema* sp.**, several genera found in **Amaranthaceae, Asteraceae, Cyperaceae, Euphorbiaceae; Melastomataceae, Poaceae, Urticaceae.**
Long lived Perennials: Stages 3–4 (7–15 yrs; 15–30 yrs)	*Acacia cornigera* L. Wild, *Ananas comosus* L. Merr., *Annona muricata* L., *Attalea cohune* C., ***Brosimum alicastrum* Sw.**, *Bucida buceras* L., *Cucurbita pepo* L., ***Bursera simarouba*L.**, *Byrsonima crassifolia* L. Kunth, *Calophyllum brasiliense* Cambess, *Carica papaya* L., ***Cecropia peltata* L.**, *Ceiba pentandra* L., *Cnidoscolus chayamansa* McVaugh, *Enterolobium cyclocarpum* Jacq. Griseb., *Guarea glabra* Vahl, *Guazuma ulmifolia* Lam., *Hamelia patens* Jacq., *Manihot esculenta* Crantz, *Manilkara zapota* L. van Royen, *Opuntia cochenillifera* L. P. Mill, *Pachyrhizus erosus* L., *Persea Americana* P. Mill, *Pimenta dioica* L. Merr., *Pouteria sapota* Jacq. Moore & Stearn, *Psidium guajava* L., ***Quercus oleoides* Schltdl. & Cham.**, *Sabal morrisian* Bartlett, *Simira salvadorensis* Standl., *Talisia oliviformis* Radlk.
Closed Canopy: Stage 5 (>30 yrs)	*Alseis yucatanensis* Standley, *Aspidosperma cruentum* Woodson, *Attalea cohune* C. Mart, ***Brosimum alicastrum* Sw**, *Bursera simarouba* L.,*Cryosophila stauracantha* Heynh. R. Evans, *Licania platypus* Hemsley Fritsch, *Lonchocarpus castilloi Standley, Manilkara zapota* L. van Royen, *Piscidia piscipula* L. Sarg, *Pouteria campechiana* Kunth Baehni, *Pouteria reticulata* Engl., *Sabal morrisian* Bartlett, *Simira salvadorensis* Standl, *Spondias mombin L., Swietenia macrophylla* King, *Talisia oliviformis* Radlk, *Vitex gaumeri* Greenman, *Zuelania guidonia* Britton & Millsp

[1] The list of taxa in each stage of the milpa cycle is based on observations by Ford and Nigh in Mexico, Guatemala, and Belize (see also Hernandez et al. 1995:242–246; Terán et al. 1998). Only native taxa are included. The dominant taxa of the closed canopy are from Campbell et al. (2006). Bolded taxa are wind-pollinated taxa found in the milpa-forest gardens and recovered in the pollen records. In many cases, the identification of the pollen is only to the genus level or higher, but the ethnobotanical field observations are to the species level. Family level identifications are included here to demonstrate that the pollen record is consistent with the data from the first stages of the milpa cycle. Since stages 3–5 are dominated by biotically pollinated taxa, there are, predictably, few taxa from these stages of the milpa cycle represented in the pollen cores.

component of land use (Terán et al. 1998). Food production continues to be important in the succeeding agroforestry phases but a critical management goal is added, focused on increasing the long-term sustainability of the system (Corzo Márquez and Schwartz 2008). Not only does cycling through forest regrowth restore soil properties, but it actually serves to increase fertility and the diversity of useful plants with each round of investment. After the first hot burn of the initial clearing for milpa, the judicious use of fire throughout the cycle increases charcoal content (Glaser et al. 2001; Liang et al. 2006), which contributes to long-term soil fertility. Careful weeding to control the seed bank composition and subsequent selection of keystone forestry species gradually shift the floral composition of the forest to favor plants valued in Maya culture (Campbell et al. 2006; Casas et al. 2007; Levy Tacher and Golicher 2004; Nigh 2008). Areas once

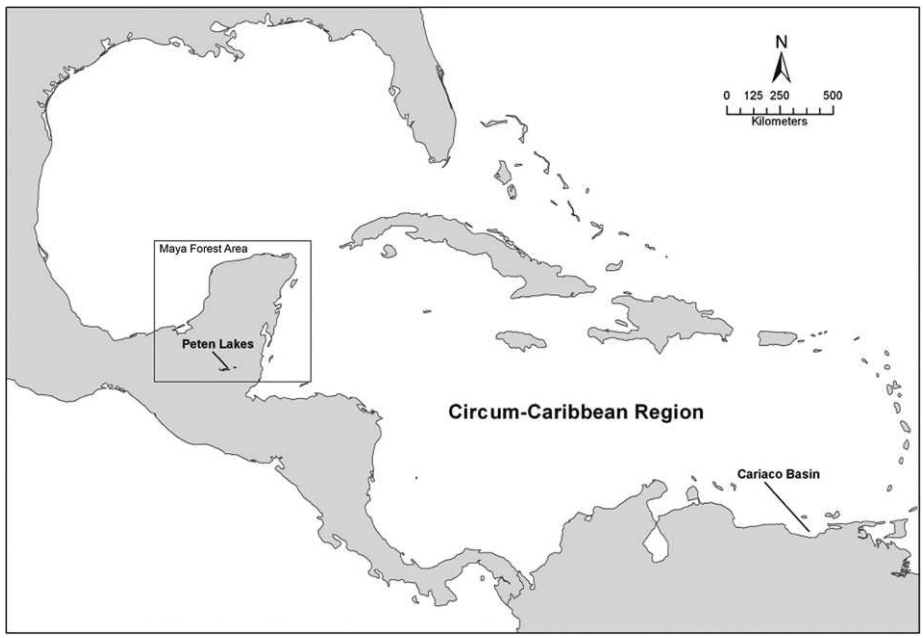

FIGURE 1. The Circum Caribbean Region and the Maya Forest Area with the location Cariaco Basin and Petén Lakes indicated.

devoted to milpa production remain under successional stages of forest cover (Finegan 2004; Zetina 2007). The ultimate result is a mosaic landscape dominated by woody species of economic importance to the lowland Maya. This is the Maya Forest garden.

The Maya and the Forest: Challenging the Extant Interpretations

We use three data sets to understand the development of the relationship between the inhabitants of the Maya area and the surrounding forest throughout the Holocene. The high-resolution sediment core from the Cariaco Basin provides information on shifts in precipitation that impact the Maya area (Haug et al. 2001; Haug et al. 2003). These data provide a backdrop for understanding the second data set—the clay deposits from the Petén lake cores—and the third data set—the pollen records from the same Petén lake cores. Linking the deposition of clay to precipitation changes and the pollen data to the development of the milpa cycle, we challenge the commonly held notion that the clay deposits and the pollen record are proxies for the destruction of the Maya Forest.

The Cariaco Basin and Regional Climate Variability

High-resolution sediment core samples from the Cariaco Basin on the northern coast of South America (Figure 1) yielded a detailed, 14,000-year proxy for precipitation with decadal resolution. Data from this core have been linked to climatic variability in the Mesoamerican and Maya area (Haug et al. 2001; Haug

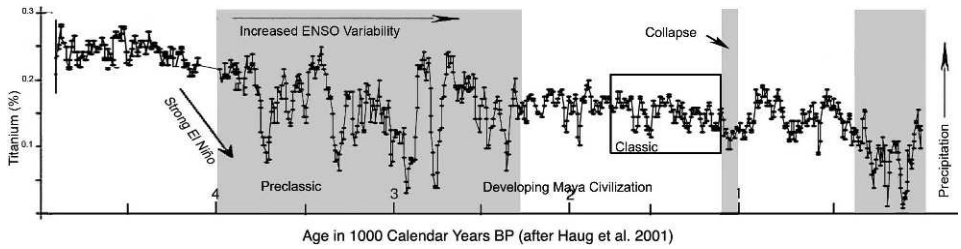

FIGURE 2. Regional Circum-Caribbean Precipitation Chart of the past 5,000 years based on titanium levels from the Cariaco Basin at the end of the Holocene Thermal Maximum. Shaded areas indicate periods of instability. Note the period of stable precipitation during the Classic period.

et al. 2003; Neff et al. 2006). We propose that the nature and timing of variability in regional precipitation was a major force of culture change about 4,000–3,000 years ago that is reflected in the foundation of Maya civilization. We are not the first to draw attention to temporal coincidence between climatic episodes reflected in the Cariaco cores and Maya cultural events. Researchers (Gill 2000; Gill et al. 2007; Haug et al. 2003) note a relationship between drought episodes and the last dated monuments at lowland Maya cities, arguing for a relationship between precipitation stress and the Maya Terminal Classic (1100–1000 BP). Once these drought episodes are examined as part of the long-term paleoenvironmental record exhibited in the Cariaco cores (beginning ~84,000 years ago; Figure 2; Hodell et al. 2008), a new perspective of Maya environmental history emerges. Viewed another way, centuries of successful adaptation to the tropical forest dwarf the importance of the temporally limited turmoil of the Terminal Classic.

Fluctuations in titanium levels measured in varved marine sediments in the Cariaco core provide a proxy for shifts in terrestrial precipitation. Such shifts in precipitation can, in turn, be associated with changes in Maya culture history (Figure 2). From about 8,000 to 4,000 years ago, titanium values reflect the climatic optimum of the Holocene Thermal Maximum, the warm, wet period within which the tropical forest expanded to dominate the Mesoamerican lowlands. Beginning around 4,000 years ago, and lasting for 1,500 to 2,000 years, the Cariaco sediment record shows a series of severe precipitation events within a larger drying trend that continues to today (Figure 2). Extremes from drought to deluge during this time have been correlated with global records including the Greenland ice cores (Peterson et al. 2000) and with an increase in El Niño activity (Rodbell et al. 1999; Sandweiss et al. 2001, 2009). The consequences of the regional precipitation stresses are visible in the data of the Petén Lake cores.

The Local Petén Lakes-Maya Clay and Fossil Pollen

In the Maya area, the ecological effects of the precipitation extremes observed in the Cariaco record are evident in the clay deposits and pollen records preserved in the Petén Lake cores. Although the Petén lake cores lack microstratigraphy, the thick detrital clay unit referred to as ''Maya clay'' and the fossil pollen record together are powerful paleoenvironmental proxies.

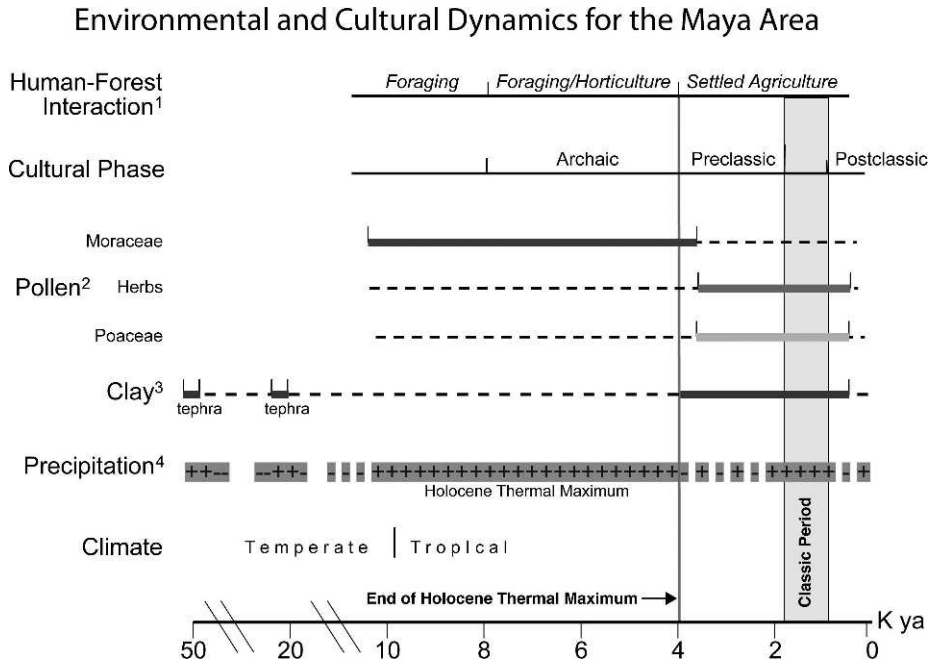

FIGURE 3. Environmental and Cultural Dynamics for the Maya area.
1. Human-forest interactions based on archaeological data in the pre-contact periods. The Classic Period represents the height of Maya civilization. The Preclassic is the time archaeologists believe marks initial colonization of this region (Rice 1996). To date, the Archaic Period is little known with recognized sites (Lohse 2009).
2. Pollen data based on Petén Lake Cores (Leyden 2002; Vaughn et al. 1985). Bolded lines signify periods of increased proportions of pioneer herbs, Moraceae, and Poaceae pollen. Based on the current assumptions (Leyden 2002), periods of high Moraceae pollen is interpreted as times primary forest, and periods with low Moraceae and high grass and herb pollen are interpreted as the periods of deforestation and, in place of forest, the establishment of open landscape.
3. Clay data based on Anselmetti et al. 2007; Brenner et al. 2002; Deevey et al. 1979; and Hodell et al. 2008. Three major episodes of clay deposition are noted in the last 50,000 years and includes two tephra layers at ~53 and ~55 ka (Hodell et al. 2008 Figures 3 & 5). Clay in record from 4000 ~ 1000 BP is termed ''Maya clay,'' however, geomorphologically, these clay events are similar (Anselmetti et al. 2007). Bolded lines indicate periods of clay events.
4. Precipitation data based on Haug et al. 2001; Hodell et al. 2008. - - - - signifies low precipitation; ++++ signifies high precipitation; Periods of relative stability provided predictability. Periods with frequent changes between (e.g., 4000 and 2000BP) were periods that were difficult for adaptation.

Previous researchers have interpreted these proxies as evidence of ancient Maya deforestation. In the following sections, we explore an alternative hypothesis to account for the Late Holocene influx of Maya clay and the changes in the pollen sequence. In particular, we suggest that the Maya clay is associated with the highly variable precipitation record noted in the Cariaco data (see Figure 2) and that the shifts in the pollen record following the influx of the Maya clay are the result of Maya agricultural strategies that developed as an adaptation to those same periods of unpredictability. In our hypothesis, neither the rapid clay deposit nor the change in pollen percentages is the result of deforestation.

Maya Clay

Maya clay, a thick, seven-meter deposit dating between 4,000 and roughly 1,000–500 years ago, has been identified in all of the Petén Lake cores (Anselmetti et al. 2007; Binford et al. 1987; Hodell et al. 2008). The temporal and spatial extent of this deposit suggests widespread and significant change across the landscape before and throughout the time when the Maya civilization was developing (Figure 3; Brenner et al. 2002; Brenner et al. 2003; Mueller et al. 2006; Rice 1996).

Although previous researchers attribute the Maya clay deposit to erosion as a result of Maya deforestation, a consequence of population growth and overextended land use (see Culbert and Rice 1990; Rice and Culbert 1990; Rosenmeier et al. 2002; Webster 2002), we are not convinced that this deposit is entirely anthropogenic in origin. We base our argument on three points. First, similar clay intrusions are found in the Petén in older lakebed sediments from 55,000–50,000 years ago and 24,000–17,000 years ago, long before the presence of humans in the area (Hodell et al. 2008:1158–1159). This indicates that similar non-human processes could have led to the deposition of what is, regrettably, called the ''Maya clay.'' Second, following this interpretation of the pre-Holocene clay deposits, we posit that the Holocene clay deposits are the result of the precipitation extremes evident in the regional Cariaco Basin record 4,000–3,000 years ago (Figure 3). Third, current study of the local Petén data demonstrates that the most of the recent influx of Maya clay specifically dates to the period *before* significant human occupation (Anselmetti et al. 2007). Thus, we argue that since Maya clay cannot be attributed solely to human-induced interaction, it is not a reliable proxy measure of human-induced deforestation.

Fossil Pollen

The pollen record from the Petén Lakes has yielded important information concerning climate and vegetation change in the Maya area (e.g., Leyden 2002:90–93). A regional shift from temperate to tropical vegetation in the late Pleistocene and Early Holocene, for example, is reflected in the Petén pollen as a shift from arid and temperate to humid and tropical taxa (Brenner et al. 2002; Hillesheim et al. 2005). Changes in the pollen record later in the sequence likewise reflect changes in the regional vegetation. These changes have also been attributed to Maya deforestation, but we argue that they are not so easily deciphered.

From the earliest paleoenvironmental studies of the Maya area, increases in pollen from the Moraceae (mulberry) family have been interpreted to indicate expansion of the tropical forest (Leyden 2002). Researchers interpreting the Petén cores have inferred that the dramatic rise in Moraceae pollen (60–80% of total pollen; Leyden 1984:201, 1987:411, 2002:91; Vaughan et al. 1985) indicates the widespread establishment of tropical forest between 8,000 and 4,000 years ago. By 4,000–3,500 years ago, the Moraceae levels drop precipitously to less than 10% (Figure 3), interpreted as an indication of deforestation. These low proportions of Moraceae remain constant from the establishment of early Maya settlements in the Middle and Late Preclassic, through the growth and development of Maya civilization in the Classic period, and beyond. Moraceae pollen rebounds at the

top of the lake cores, perhaps as recently as 500 years ago, after the Spanish conquest (Leyden 2002:91).

There are, we suggest, major problems with the current models that equate the rise and fall of Moraceae pollen in the Petén cores with the rise and decline of lowland forest cover. First, Moraceae is a family-level identification, yet some researchers (e.g., Binford et al. 1987; Rice 1996; Webster 2002:256) assume it represents *Brosimum alicastrum*, a species within this family that dominates the contemporary pollen rain (Leyden 1987, 2002). These researchers have, in turn, used the presence of *B. alicastrum*, commonly known as *ramón*, to indicate change in forest cover. While *B. alicastrum* is one of the dominant canopy trees in the forest today (Campbell et al. 2006), without a clear relationship between Moraceae and the forest, the changes in Moraceae pollen, or by inference *Brosimum* spp., cannot be reliably used to distinguish changes in vegetation across the landscape (see McKillop et al. 2009 for a similar problem with red mangrove).

Complicating matters, the family Moraceae includes a variety of species that populate both forested and unforested ecosystems. For instance, *Cecropia* (recently changed to Urticaceae), as well as *Chlorophora*, and *Ficus* (see Leyden 2002; Rosenmeier et al. 2002) are successional taxa, tolerant of high light conditions typical of pioneer taxa (Strauss-Debenedetti and Bazzaz 1991). Thus, Moraceae pollen, associated with a wide variety of habitats, is unlikely to be a signal only for older forest cover.

Finally, because of the dominance of wind-pollinated taxa in the pollen record of the Petén lake cores, the record cannot represent the actual floral composition of any forest type, including the Maya Forest garden. Absent from the cores are the 98% of forest species, which are pollinated by birds, bees, and bats; only the approximately 2% of the forest taxa are wind pollinated and thus potentially represented in the cores (Kellmen and Tackberry 1997:18; Turner 2001:130). Similarly, few of the taxa that make up the Maya Forest garden are wind pollinated (Table 1; see also Ford 2008). *Brosimum alicastrum* is wind pollinated, grows in the forest and the forest gardens of the region (Ford 2008), and is known to have been managed by the Maya (Peters 2000), yet its variability in the record cannot be tracked, especially with the family level identification of Moraceae. Consequently, the pollen record is a poor proxy measure for the existence of managed forests, or indeed for the majority of economically important plants of the tropics. For instance, plants that are pollinated by insects, such as avocado (*Persea americana*), recovered in the archaeological record dating to more than 7,000 years ago (McClung 1992), are unlikely ever to be represented in pollen records extracted from large catchment lakes.

Thus, while we agree that pollen cores can be used to track human-forest relationships in general, we propose an alternative interpretation of the nature of this relationship for the Maya case. Specifically, we suggest that the record reflects, in part, the vegetation communities of the milpa cycle and the resultant Maya Forest garden. The wind-pollinated taxa that grow in the first stages of the milpa cycle (Stages 1–2; Table 1) are well represented in the pollen cores (Leyden 2002; Vaughn et al. 1985). These early successional taxa, therefore could represent the open stages of the milpa cycle rather than a deforested landscape.

The later succession stages of the milpa cycle (Stages 3 and 4, Table 1), are represented in the cores by the pollen of plants such as *Cecropia*. Later closed canopy stages of the milpa cycle, dominated by zoophilous fruit trees (Table 1), are, predictably, absent in the pollen records (Ford 2008:188). We do not, however, equate their absence in the record with their absence on the landscape. These fruit trees would have been an integral part of the ongoing regeneration process that is fundamental to the milpa cycle and the resultant Maya Forest garden.

Taken together, we suggest that the evidence for early successional vegetation in the pollen cores and domesticates in the paleoethnobotanical record are all consistent with evidence for the milpa cycle and the Maya Forest garden – a resource management system that supported a patchwork of open fields and closed canopy orchards. This system, we propose, evolved under the constraints of precipitation uncertainty and persists among traditional Maya farmers today as the Maya Forest garden.

The Ancient Maya Chronology

Based on our compilation and reinterpretation of the paleoenvironmental data, we summarize below our proposed model of the development of management strategies used by the Maya and their ancestors. We divide our model into the standard culture historical divisions used for this region (Archaic, Preclassic/Early Formative, Classic), but focus specifically on human-forest interactions (Figure 3). In this overview, we track the proposed development of highly managed forests beginning with the low-level food production in the Archaic (8,000–4,000 years ago), followed by the establishment of the milpa cycle and the resultant Maya Forest garden in the Preclassic/Early Formative (4,000–3,000 years ago), and finally the intensification of this forest management system during the Classic period (2,000–1,000 years ago).

The Archaic Foragers

Our understanding of human-environmental interactions during the Archaic period is hampered by a scant archaeological record (see Clark and Cheetham 2002 for summary; Lohse 2009; Lohse et al. 2006; MacNeish 1982). Not surprisingly, few sites are known from this period because low density, mobile human populations are difficult to detect archaeologically. Nevertheless, archaeological data for the greater Mesoamerican region, the context for the Maya area, indicate that as early as 8,000 years ago people combined early horticulture (maize, beans, squash, and chile) with hunting and gathering (Betz 1997; Clark and Cheetham 2002; McClung 1992; Piperno and Pearsall 1998; Smith 1998). This indicates that plant management and domestication long preceded the settled agrarian life that characterizes the later Mesoamerican and Maya culture (Colunga Garcia Marin and Zizumbo-Villareal 2004).

We propose that from 8,000 to 4,000 years ago, during the Holocene Thermal Maximum, resident foragers interacted with the expanding tropical environment during a time of high precipitation and climatic stability (Figure 2 and 3; Haug et al. 2001). The relatively stable climatic pattern of consistent high precipitation

would have allowed dispersed populations to use the landscape over a broad area rather than restricting them to concentrate in naturally moist zones. During this stable period, we suggest people became increasingly knowledgeable of, and connected to, the tropical forest ecosystem.

This human-forest interaction would have included the selection for and management of desirable species that are part of the Maya Forest garden today. In addition, people would have experimented with various cultivation techniques—planting, weeding, tending—that would have increased the abundance and availability of economically important plants, including domesticates. Based on data from elsewhere in Mesoamerica, these early domesticates included squash, beans, chile, and maize (McClung 1992:149–151; see also Casas et al. 2007; Piperno and Stothert 2003; Pope et al. 2001; Smalley and Blake 2003). We propose that over this 4,000-year period, human interaction would have resulted in a landscape that was, in parts, highly managed. These management strategies would have been both ecologically subtle and spatially discontinuous, making them difficult to detect in the coarse paleoecological record.

However, when the paleoecological data from the Petén Lakes (Brenner et al. 2003; Leyden 2002; Vaughn et al. 1985) are interpreted in light of the ethnobotanical data on the milpa cycle, it can be used to support our model for forest management by the Archaic peoples. Based on the lake core pollen reported by Vaughn, Leyden, and others, we suggest that the Archaic environment included concentrations of the same economically important arboreal and shrub taxa that are so prevalent in the neotropics today. Open ecosystems composed of early successional plants would account for the presence of such plants in the pollen cores (e.g., *Ambrosia*, *Cecropia*, *Mimosa*, *Trema*, and members of the Amaranthaceae, Asteraceae, Cyperaceae, Euphorbiaceae, Melastomataceae, Poaceae, Urticaceae). Adapted to the mobility of the population, such a forest management dynamics would be attuned to the natural regeneration of the forest.

The Preclassic/Early Formative Cultivators

The start of the Preclassic, 4,000 years ago, is marked by the first appearance of residential sites and an increased reliance on domesticated crops, the shift to settled life, and the use of ceramics in Mesoamerica and later the Maya area (Blake et al. 1992; Clark and Cheetham 2002:283–286; Voorhies 1998). During this time, changes in the pollen and sediment records indicate that the climate of the Maya area was highly erratic, moving between multi-year extremes of drought and deluge (Haug et al. 2001, Figure 2 and 3). Beginning around 3,000 years ago, the drying trend would have restricted water availability in the porous limestone Maya lowlands, particularly in the deficit periods (Ford 1996). As a result, people concentrated their settlements and subsistence activities to take advantage of localized water sources on or near the agriculturally productive ridges and hills (Fedick 1989; Ford 1986, 1991; Puleston and Puleston 1972; Rice 1976; see also Neff et al. 2006). This land-use pattern was an intensification of the mobile horticultural practices of the preceding Archaic peoples. As suggested by pollen evidence, this pattern represents the initiation of milpa-style agriculture. We

propose that over time, the practice of the milpa cycle spread and was the foundation of early Maya cities, such as the well-known centers of Nakbe and Mirador (Clark and Cheetham 2002; Forsyth 1993a, 1993b; Hansen et al. 2002).

Intensification of Production During the Classic Period

The Classic period (1,750–1,100 years ago) heralds the rise of the Maya civilization, characterized by extensive social and economic hierarchies. Large, dense settlements are found in all well-drained areas (Ford et al. 2009), the same areas that were the focus of occupation in the Preclassic (Fedick and Ford 1990). This period is marked by a climatic regime that was more stable than during the Preclassic (Figures 2 and 3). This climatic and environmental stability allowed for a growing agrarian population as demonstrated archaeologically by the infilling of the preferred settlement areas—the well-drained, fertile hills and ridges (Ford 1986). This process continued throughout the Classic, and by the Late Classic (1400–1100 years ago) these areas contained more than 80% of the settlements (Fedick and Ford 1990; Ford et al. 2009), even though they make up less than one quarter of the Maya landscape. The agricultural field systems, characterized by the milpa cycle and forest gardens, supported these permanent residences (Netting 1977; Zetina 2007). Intensification of production at this time is reflected archaeologically by the expansion of land use into marginal areas and the development of terracing and drainage (Healy et al.1983; McAnany and Harrison 2004).

Our knowledge of Maya ethnoecology suggests that many intensification strategies likely were also used, but these would be difficult to detect in the archaeological or paleoecological records. These strategies include decreasing fallow times (Johnston 2003); increased selection for economically significant plants (Campbell et al. 2006); heightened investment in polycultivation (Nations and Nigh 1980; Terán et al. 1998) and tree cropping (Gomez-Pompa 1987); the development of labor and management skills (cf., Bray 1994); and refining ecological knowledge of ''weeds,'' insects, and soil amendments (Gliessman et al. 1981). This complex set of skills and ecological knowledge, we propose, built on those gained during the more climatically erratic Preclassic period. Collectively, these strategies resulted in low risk, highly stable managed ecosystems that characterize the Maya Forest garden.

The extant paleoecological evidence supports this interpretation of agricultural intensification. A decline in Moraceae pollen may be testimony to selective encouragement of and management for more highly valued tropical fruiting trees such as avocado, mahogany, allspice, mamey and zapote. These tree taxa are significant components of today's forests and forest gardens, but since they are animal pollinated, they are absent in the lake core records. The herbs and grasses are also consistent with a well-developed milpa cycle (Table 1), representing the open stages of this resource management system. Taken together, this evidence supports the hypothesis that these management strategies developed into an integrated, productive, and flexible resource management system. This system provided for the subsistence needs of a growing population, as well as supported the maintenance and regeneration of the landscape.

We see this dynamic land-use system as a critical component of the resilience of the Maya Forest garden. The settlement pattern data along with the lake core pollen and sediment records point to the management of resources across the landscape (e.g., Johnston 2003; Kunen et al. 2000; see also Terrell and Hart 2008; Terrell et al. 2003). Infield orchards and gardens would have been associated with dense permanent settlements whereas milpas would be associated with dispersed temporary settlements. These settlement patterns, known for the ancient and contemporary Maya (Fedick 1992; Ford et al. 2009; Zetina 2007), are consistent with the management of the forest to field continuum of the milpa cycle (Table 1). Recent research on ancient Maya settlement in the El Pilar area shows that 40% of the landscape was unsettled, yet given the presence of economic species in those area, one would consider that these areas were incorporated into the management regime (Ford et al. 2009). Unoccupied areas would have provided refuges for animals less tolerant of human presence, such as jaguar and tapir, as well as managed resources such as *Haematoxylon campechianum*, the logwood or tinto tree, which serves as a basis for dye and was used for lintels at Tikal (Orrego Corzo and Larios 1983). Overall, the Maya Forest environment was a patchwork composed of open urban and residential areas, cultivated fields and orchard gardens, and managed closed canopy forests. Each of these patches would have cycled from forest to field and back again. Collectively, over time and across space, this is the Maya Forest garden.

Putting it All Together: Climate Change, Forest Change, and the Management of the Maya Forest

The complex structure of the Maya Forest today is, we propose, in large part a legacy of the long-term adaptation of the ancient Maya and their ancestors to their surroundings. Our investigation of the paleoclimatic, geomorphological, paleobiological, archaeological, ethnological, and ethnobiological data suggests that the conventional models about land use among the ancient Maya are untenable. We offer an alternative model focusing on the development of a forest management system that links to data on the contemporary forest as well as traditional knowledge and skill today. In the future, our model can be evaluated with new data and new methods, just as we have re-evaluated the conventional model in this paper (Table 2).

Combining the regional precipitation record with the changes in the local sediment records, as we have done here, provides new insights into local Maya response to climate change. In early studies of the Maya paleoenvironment during the Holocene, the rise of the Maya civilization was acknowledged to be the only significant cause of change to the ecology of the area (Deevey et al. 1979; Rice 1996). It was implied in these studies that there was no occupation in the Maya Forest before the archaeologically visible settlements of the Preclassic. We suggest, however, based on more recent understanding of Mesoamerican cultural developments, that humans have a long-term relationship with the tropical forest that began with foragers in the Archaic period. In our proposed model, these foragers developed an intimate knowledge of their landscape over several millennia of stable climatic conditions. We suggest that the ecological knowledge,

subsistence, and settlement patterns that developed during this time were viable as long as the rainfall was consistent and predictable.

Four thousand years ago there was a change in climate, and for at least next 1,500 years, rain was erratic and unpredictable compared to the previous millennia. The initiation of this climatic instability is dramatically recorded in the Petén lake cores by the influx of Maya clay and change in the pollen record. During this time, flora and fauna were stressed, leading to changes in ecosystem composition. For humans, we propose that in the dry periods the porous limestone of the Maya area would not support surface water collection. As a result, the scattered populations of the Archaic were challenged to concentrate on the ridges and hilltops where all basic subsistence resources of water and food converged.

We hypothesize that the ancestral Maya foragers responded to this period of unpredictable precipitation by relying less on foods of the forest and instead intensifying the management and horticultural component of their subsistence system. This, in turn, fostered the establishment of permanent settlements and eventually, the highly managed, anthropogenic landscape we call the Maya Forest garden. This resource management system focused settlements in the location of the productive resources (Fedick 1989), and fueled population growth and centralization that evolved into the elaborate Maya civilization. Other resources were managed from settlements and intensified into a mosaic management system that is reflected in the composition of the contemporary forest and used today among traditional farmers.

Thus, rather than the initiation of a period of ''escalating environmental disturbance'' (Dunning and Beach 2000) and ''widespread deforestation'' as a consequence of increasing human population (Binford et al. 1987; Diamond 2005; Rice 1996), we see the Classic period as a time of renewed cultural and ecological stability. The hard won adaptation of the resource management system developed in the Preclassic evolved into the intensified forest garden-milpa cycle practiced on the preferred well-drained uplands of the Maya Forest. The pollen record is consistent with this interpretation.

The achievements of the Classic Maya civilization, with artisans, scholars, and rulers, speak to the prosperity of the system. The extravagance of the civilization, however, broke down in the Terminal Classic, perhaps associated with destabilizing droughts, warfare and abandonment of the civic infrastructure (Gill et al. 2007; Rice et al. 2005). Even so, the milpa cycle and the resultant Maya Forest garden persisted and are reflected in the botanical composition and the traditional knowledge of the forest today (Atran 1993; Campbell et al. 2006; Gómez-Pompa et al. 2003).

Our proposed hypothesis of the origins of the Maya resource management system requires new data, new approaches, and evaluation (Table 2). To understand the change in settlement patterns from the Archaic to the Preclassic, we need to have more attention to surveys that can identify the Late Archaic sites as well as the initial Preclassic settlements. This will involve the focus on the hydrology of the Maya Forest region, since precipitation is identified as the principal stress among other environmental variables. To document the long-term human-environment relationships, the application of innovative techniques

TABLE 2. Accepted Assumptions and Alternative Hypotheses on Human-Environment Interactions in the Maya Forest.

Accepted Assumption	Critique	Alternate Hypothesis	Data/Approach Needed to Evaluate Alternatives
Prior to 3000YBP and the development of the Maya Civilization, the Maya Forest was unoccupied (Rice 1996)	Prehistoric sites are widespread in Mesoamerica (Steele et al 1998), why would the lowlands be avoided? Archaic sites would be difficult to find Sparse archaeological evidence suggests earlier human occupation (e.g., Lohse 2009; Lohse et al. 2006; MacNeish 1982; Pohl et al.1996)	Archaic populations adapted to all ecological zones of Mesoamerica, including the Lowlands and were in low densities presently undetected	Surveys designed to detect evidence of non-sedentary and semi-sedentary people
Human-forest interactions began in the context of the Maya Civilization with intensive agriculture	Mesic forest plants (avocado) recorded in arid archaeological contexts by ~7,000 YBP (McClung 1992) indicate long human forest interactions	Archaic adaption included low-level food production (Smith 2001) of forest taxa (including tending/manipulating forest resources).	Application of diverse and innovative techniques to detect plant management (e.g., Lepofsky and Lertzman 2008).
Post 3000YBP Maya agricultural clearing caused the erosion event called ''Maya clay'' (Anselmetti et al. 2007)	Equivalent clay deposits are recorded at times prior to human occupation and associated with tephra layers (Hodell et al. 2008)	Since clays geomorphologically similar to ''Maya clay'' pre-date human occupation with known climatic causes, climate as well as human activity caused the depositional event resulting in the Maya clay	Quantify the temporal association of clay deposits with charcoal counts (as a proxy measure of human-set fires) Quantify the temporal association of clay deposits with glass shards (as a measure of volcanic influx).
Post 3000YBP decline of Moraceae pollen in lake cores is evidence of widespread deforestation (Binford et al. 1987; Rice 1996)	Moraceae pollen is a poor proxy for forest composition Pollen records poorly represent forest composition since >90% of forest taxa are not represented in pollen records (Ford 2008)	Human adaptation to climate change selected for fruiting taxa and families that are not wind pollinated and will not show up in most pollen records (e.g., Anacardiaceae, Apocynaceae, Boraginaceae, Fabaceae, Laureceae, Meliaceae, Myrtaceae, Sapotaceae)	Conduct focused paleoethnobotanical studies designed to recovered macro and microbotanical remains of economically important taxa in archaeological record Collect pollen from small hollows that will show a local pollen signature

TABLE 2. Continued.

Accepted Assumption	Critique	Alternate Hypothesis	Data/Approach Needed to Evaluate Alternatives
Post 3000YBP increase in herb and grass pollen in lake cores is evidence of conversion of forest to savanna (Leyden 2002; Vaughn et al. 1985)	Identification of wind pollinated grass and herb taxa is also consistent with increase in habitation, milpa, and forest gardening	These varied taxa are part of a resource management mosaic based on the Forest Garden-Milpa cycle (Table 1)	Document association of forest garden with milpa taxa in the paleoethnobotanical record.
Post 3000YBP Maya interaction with the environment resulted in the ''destruction'' of the forest (Deevey et al. 1979; Diamond 2005)	The Maya Forest Maya Forest is replete with economic trees that develop in consort with the milpa cycle (e.g., Atran 1993; Campbell et al. 2006; Gomez-Pompa and Kaus 1992)	The contemporary traditional Maya land use is the product long tern resource management skills and strategies (Atran et al. 1999; Terán et al. 1998)	Conduct focused paleoethnobotanical studies designed to recovered macro and microbotanical remains of economically important taxa.

to detect plant management need to be brought to the fore (e.g., Lepofsky and Lertzman 2008). This could involve understanding both the contribution of protein in the ancient diet (Emery and Thorton 2008) as well as the intimate ecological knowledge of contemporary Maya (Atran 1993). Analyses of the components of ''Maya clay'' are essential to determine whether it originated locally or from other sources such as airfall tephra (cf., Hodell et al. 2008). These analyses also require determining the sources of the local clay. More detailed study of charcoal is needed to help differentiate natural versus human-set fires. Finally, the clear signature of Moraceae pollen that rises in the Holocene Thermal Maximum and declines over the course of the development of the Maya civilization needs to be unpacked. Paleoethnobotanical analyses that identify local plant use (e.g., Jacob 1995; Jacob et al.1996; VanDerwarker 2005, 2006) could in turn be compared to the more general data from the lake cores. As well, a more comprehensive understanding of the relationship between pollen rain and the trees in contemporary forests would enable us to better interpret the ancient pollen record.

Taken together, our alternative perspective on the ancient Maya resource management system provides new insights into the complex and long-term history between people and the Maya Forest. Indeed, our ability to conserve this ecosystem today depends on this understanding.

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